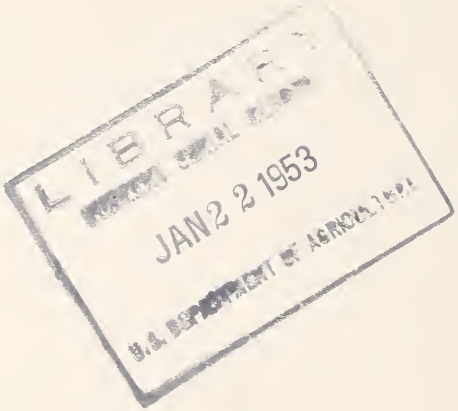
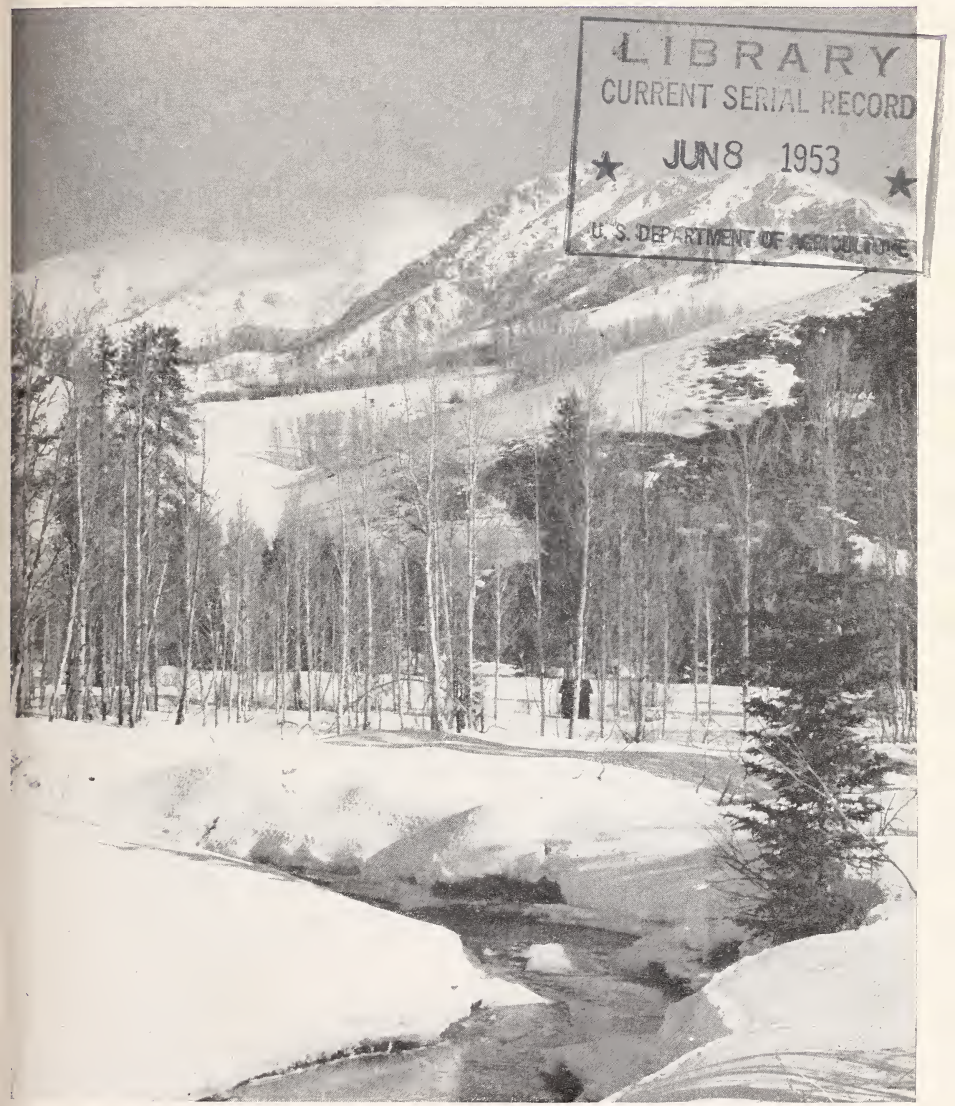
Historic, archived document

Do not assume content reflects current scientific knowledge, policies, or practices.


LIBRARY
JAN 2 2 1953
U.S. DEPARTMENT OF AGRICULTURE

Stream-flow FORECASTING FROM SNOW SURVEYS



UNITED STATES DEPARTMENT OF AGRICULTURE
Soil Conservation Service • Circular No. 914

Circular No. 914

March 1953 • Washington, D. C.

UNITED STATES DEPARTMENT OF AGRICULTURE

Stream-Flow Forecasting From Snow Surveys

By R. A. Work, *snow survey project supervisor, Soil Conservation Service* [1]

CONTENTS

	Page		Page
Introduction	2	Snow surveys as an aid in estimating peak flows	9
Multiple-use reservoirs in a coordinated flood-control program	3	Relation of flow volume to peak flow	10
Measuring the snow cover	5	Estimating the peak flow	10
Application of snow surveys to stream-flow forecasting	5	Benefits of stream-flow forecasting	15
Forecasting the total seasonal flow volume by snow surveys	8		

INTRODUCTION

Winter's snow, quietly sifting down in remote forest places, normally provides much of the life-giving water needed by thirsty western lands. The hum of power lines and the whirring wheels of industry reflect each melting flake. Busy municipalities absorb the runoff from melting snow. The works of man prosper and expand from nature's refrigerating cycle—water to snow to water. Snow minus heat stores far more water than any man-made reservoir ever conceived; snow plus heat, together with rainfall, provides water for use by man.

When this cycle departs notably from the normal, the forces thus unleashed may be extremely detrimental to man. In the western United States, river systems lacking a normal cover of snow over the far-flung watersheds may shrivel to unproductive flows, even during periods of greatest need for water. Conversely, watersheds may become so winter-burdened with snow that the melting accumulation suddenly releases water in volume sufficient to produce destructive floods.

Through forewarning of such extremes, skillful planning and swift action may convert impending disasters to merely unfavorable situations. The Soil Conservation Service of the Department of Agricul-

[1] Data and computations used in this report were furnished by H. G. Wilm, U. S. Forest Service; M. W. Nelson, Homer Stockwell, Gregg Pearson and A. R. Codd, snow survey leaders, Soil Conservation Service; and R. T. Beaumont, Oregon Agricultural Experiment Station.

ture and the Weather Bureau of the Department of Commerce are the two national agencies actually concerned with observing, gathering, and processing the data for these forewarnings. This Circular is primarily concerned with the operation of snow surveys by the Soil Conservation Service for this purpose and the manner in which snow-survey measurements are used to forecast runoff. It sets forth also the uses and benefits of runoff forecasts.

MULTIPLE-USE RESERVOIRS IN A COORDINATED FLOOD-CONTROL PROGRAM

In recent years there has been an increasing recognition of the intimate relationships between land and water. It is becoming more and more evident that activities directed toward the prevention of floods or the reduction of peak flows should include land treatment and watercourse structures on the headwaters of streams, thus complementing the flood-control activities on the main streams. Unquestionably, much can be accomplished toward the reduction of damaging peak flows through proper watershed management, conservative use of forest and range lands, and agronomic practices designed to reduce or retard runoff on cultivated lands.

Important as these aspects of stream-flow control are in the general flood problem, this publication makes no attempt to cover them in detail. It should be noted, however, that the proper use and treatment of watershed lands, when widely applied, will in time appreciably change the runoff characteristics of tributary streams.

With increasing development of western rivers for irrigation and power generation, more and more reservoirs are being used for multiple purposes and are available for use in helping to control or prevent floods. As a result there is an increasing demand for accurate forecasts of runoff which will make possible the most efficient multiple use of the reservoirs. For irrigation and power, the need is mainly for estimates of the probable total volume of water and its seasonal distribution. For flood control, estimates of the most probable maximum volume flows are needed.

With the aid of dependable forecasts of both water yield and peak flow, extreme flood peaks can often be reduced by storing the water captured in reservoirs primarily designed and constructed for irrigation or power uses. If the forecast makes clear that a large water yield is to be expected during early summer, water in reservoir storage could be released early in the season, and put to beneficial use where needed, with assurance that it would be replaced later with water from snowmelt. Such storage of water from the snowmelt reduces the peak discharge below the reservoir. Unless storage space is available, flood flows sweep through full reservoirs and exert their full destructive force along the stream channels below.

The use of Grand Coulee Reservoir for flood control in 1949 is credited by the U. S. Corps of Engineers with reducing the flood stage of the Columbia River backwater in Portland Harbor by 0.6 foot. In 1950 skillful manipulation of the flood-control services of this reservoir reduced the stage of the lower Columbia at Vancouver, Wash., by about 1.4 feet. In 1950 all of the major irrigation reservoirs in the Columbia Basin operated by the U. S. Bureau of Reclamation also were used for flood control. Total control by all reservoirs,

235099—53

FIGURE 1.—Use of snow-survey sampling equipment: *A*, Driving the snow-sampler tube to obtain a core of snow for determining water content; *B*, weighing the snow sample to determine how much water is in the snow.

including Grand Coulee, was estimated to have reduced the flood stage of the lower Columbia River at Vancouver by almost 2 feet. The Corps of Engineers and Bureau of Reclamation jointly calculated that this reduction of flood stage prevented property damage which, lacking regulation, would have exceeded 5 million dollars.

MEASURING THE SNOW COVER

The water content of the snow cover at a given location is reliably determined by measuring the water content of the snow at several points along a snow course. A snow course consists of a series of observation points, usually 10 or 12 in number or enough to give a dependable sampling average. These points are situated at measured spacings of 50 or 100 feet along a permanently marked and mapped route, usually about 1,000 feet long. The courses are usually located in small mountain meadows. The samples are taken and water content is determined at the same locations on each measuring date, year after year. The work is done by a small, skilled corps of professional snow surveyors trained in mountaineering and in travel of all kinds over snow.

The snow sampler is a lightweight seamless aluminum tube consisting of easily coupled 30-inch sections. The bottom section is tipped with a circular saw-edged cutter for penetrating hard snow or icy crusts.

The sampler is forced vertically through the snow to the earth beneath (fig. 1, *A*) and the depth of snow is recorded easily from 1-inch graduations stamped on the sampler. The tube with its contained snow core is weighed on a small and amazingly simple scale from which the quantity of water in the snow, in inches, is determined (fig. 1, *B*). The sampler is so designed that 1 ounce of snow core is equal to 1 inch of water depth. The snow core taken in this manner is a mixture of water and air, but the significant numerical value obtained from the snow survey is the average water content of the snow layer.

It is important to note that the snow surveys do not necessarily measure the total volume of water stored as snow within a drainage basin. They measure, instead, the water content of the snow cover along the related snow courses. The information from a few snow courses in a large drainage basin thus provides an *index* to the snow-water accumulation over that watershed.

APPLICATION OF SNOW SURVEYS TO STREAM-FLOW FORECASTING

Snow surveyors are accustomed to measuring large quantities of water stored in snow, especially in the towering Sierra Nevadas of California, the remote Cascades of Oregon and Washington, and the rough coastal range of British Columbia. Snow depths of 150 inches storing water contents of 50 or more inches on April 1 or May 1 are not uncommon in these areas. Figure 2 shows the typical snow cover of high mountains.

However, should 50 inches or more of snow-stored water be measured on April 1, or thereabouts, at a location where not more than 30 or

FIGURE 2.—Deep wet snow—Nature's promise or threat?

possibly 40 inches has previously been recorded at that date, there may be cause for serious concern. Stream flow from such a snow cover will be materially greater than average—whether for irrigation, power, navigation, municipal needs, mining, or other uses. The unusually high water content of such a snow cover may also represent a potential flood hazard. About a month later, and perhaps again at a later date, the snow surveyors resurvey the snow cover to determine again an index to the water remaining in the mountains.

Speed, accuracy, and practicality are essential in analyzing snow-survey data and reporting results if water-supply forecasts are to be of greatest use. In far-away offices of the Soil Conservation Service—the national agency coordinating snow surveys for water-supply forecasting in the Western States—experienced engineers rapidly piece together and analyze the snow-survey reports pouring in from a thousand or more high mountain places. A cooperative arrangement with the U. S. Weather Bureau provides for the pooling of all data—both snow survey and precipitation measurements—and the coordination of all water-supply forecasts. Field and office methods have been developed which make it possible to furnish to water users preliminary or final water-supply forecasts in no more than 4 or 5 days after completion of the distant mountain snow surveys. There is continuous coordination with the river service offices of the Weather Bureau in the issuance of joint statements of flood potential based on the combined data of the two agencies. Survey leaders communicate constantly with groups of water users to find out their specific needs for forecasts.

Reports of snow cover, quantity of water in snow storage, and related conditions are rushed to offices of operating agencies having responsi-

bility to control or combat river flows. These agencies have on hand in general outline alternative plans for water regulation and use against the day when they come to know with certainty how much snow water, delicately balanced for release, is present on the avalanche-breeding slopes and in the mountain cirques and remote forest glades (fig. 3). The successive reports of snow cover and precipitation and the successive water-supply forecasts revised on the basis of more recent data enable the interested agencies to complete their operating plans in more specific detail.

The snow surveys are made primarily to forecast water supplies for irrigation. The dates of the surveys are therefore fixed so as to be of greatest advantage to users of irrigation water. For many watersheds of the snow-flood streams of the West, April 1 is a suitable date for the initial forecast. For optimum use in runoff forecasting on these watersheds, the April snow surveys should be supplemented by additional surveys later in the spring to reveal conditions on April 15, May 15, June 1, and probably also June 15.

Although an early-season snow survey may reveal the presence of heavy accumulations of mountain snow, this does not necessarily mean that a destructive flood is bound to occur. It means, rather, that one of the basic conditions giving rise to stream flows of serious proportions on snow-fed rivers is present and that a damaging snowmelt flood may develop. As the season moves on, the probability of flood may either dim out or become so great as to constitute a practical certainty. The periodic surveys after April 1, together with the progressively revised forecasts which take into account weather changes from day to day, narrow down the range of probable flow volume. As conditions become more definite, the Weather Bureau—

FIGURE 3.—Snow melt beginning in the high country.

the agency responsible for public flood warnings and river-stage forecasts—shifts from issuing general warnings to detailed forecasts of daily and crest stage in time and place. These are based on current reports of the hydrologic and meteorological conditions within the basin (including the available snow-survey measurements) and on forecasts of anticipated precipitation and temperature.

FORECASTING THE TOTAL SEASONAL FLOW VOLUME BY SNOW SURVEYS

Mountain snow surveys are utilized in forecasting the probable total seasonal volume of flow of rivers—including those subject to floods from snowmelt—in advance of the main spring and summer runoff. The use of snow surveys for this purpose is based on the fact that (1), most of the snow at high elevations falls in a few major storms which usually are uniform in intensity over large areas; and (2), the water content of snow accumulated under these circumstances, as measured at representative snow courses on a watershed, has a direct relation to later runoff from that specific drainage basin.

The method consists essentially of correlating the water content of the snow pack in the mountains each year with the resultant flow volumes. The water-content measurements provide an index—not a direct estimate—of the amount of water in the snow cover of the entire drainage area which is then related to the runoff to obtain for a given watershed the basic relationship between snow cover and runoff. The relationship between the water content of the snow cover and the runoff is usually determined for specific periods for which runoff information is of special interest or importance, such as April-June, April-September, or other period of significance. The relationship varies somewhat for different periods. But as each succeeding year's record becomes available, the basic relationship for any specific period can be more precisely determined.

For a given drainage area this relationship may be shown in a simple manner by plotting on a graph both the water content of the snow and the corresponding resultant seasonal runoff for each year for which dependable data on snow-water content and runoff volume are available. A graph is prepared to show this relationship at date of peak accumulation of snow-water content (usually April 1). On the graph a best-fit line, sometimes called regression line, is drawn through the plotted points as a snow cover-runoff curve (fig. 4).

Figure 4 illustrates the basic snow cover-runoff relationship for the North Fork of the Rogue River in Oregon, as determined on the basis of conditions in the watershed above Prospect, Oreg. The yearly value for snow-water equivalent used in the preparation of this curve in each instance is the maximum water content accumulated in the snow pack for the winter regardless of whether that accumulation occurred early or late in the winter. The resulting line of best fit becomes more reliable with each succeeding year's entry of new records.

To forecast the runoff from this particular watershed for a given year, once the water content of the snow cover is known, the measured water content as obtained by the snow survey is located on the water-content (vertical) scale of the graph. A line is projected horizontally from this point to the snow cover-runoff curve, and is then dropped to the horizontal (runoff) scale. This permits direct reading of the fore-

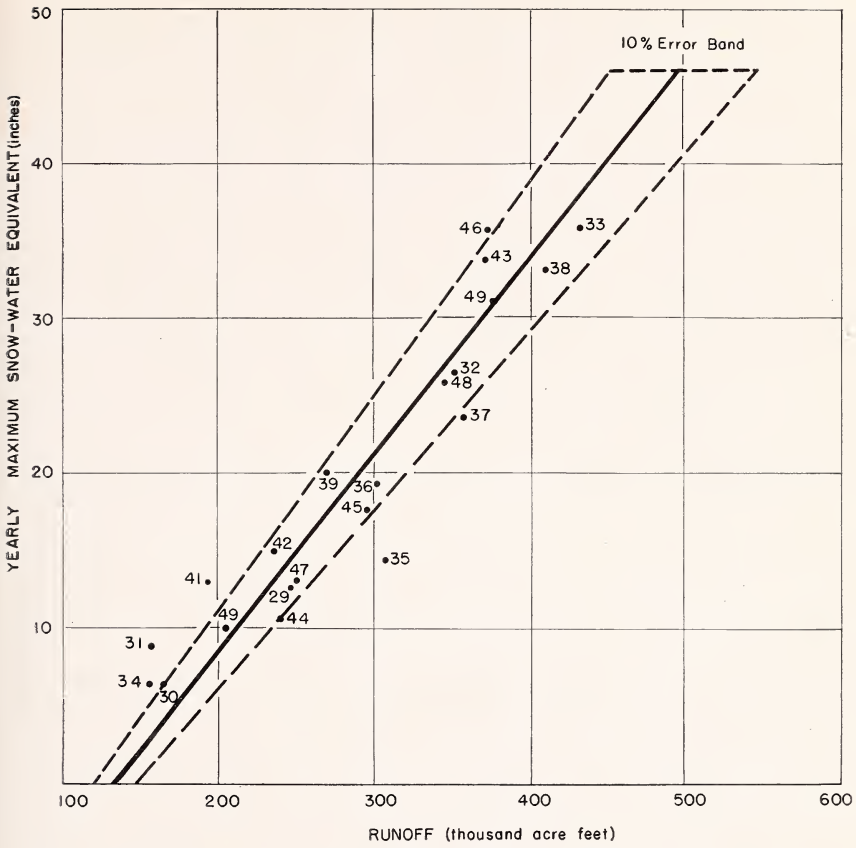


FIGURE 4.—Relationship of snow cover on Diamond Lake, Oreg., snow course to April-September runoff volume of North Fork Rogue River above Prospect, Oreg.

cast value from the runoff scale. This runoff value may require minor adjustment to allow for abnormal conditions in the snow areas, in years when such conditions are important enough to affect the basic snow cover-runoff relationship. These unusual circumstances may include abnormally high or low precipitation before the snow-accumulation period, abnormal winter temperatures, or abnormal distribution of snow cover with respect to altitude or slope aspect. They may also include any marked change in the snow-retention capacity of the watershed due to extensive timber harvesting, forest fires, overgrazing, or land clearing.

SNOW SURVEYS AS AN AID IN ESTIMATING PEAK FLOWS

Water users and others whose occupations and pursuits depend upon the supply of water from snow-fed streams are interested not only in the total quantity of water that will be available. They are also vitally concerned with the manner in which the flow of water will be delivered. Will the major part of the water supply arrive fairly

evenly during the runoff season, or will the bulk of the flow be concentrated in a relatively short period? And if the latter, what is the *greatest* amount of water—the peak flow—to be expected during the main runoff period?

Snow surveys, in addition to their use in the determination of runoffs and water supplies, are an aid in estimating peak stream flows.

Relation of Flow Volume to Peak Flow

The peak flow of snow-fed streams is closely related to the total volume discharge of such streams through the principal period of snowmelt. This is because streams which derive their principal runoff from snow fields deliver the greater part of their annual runoff during the very few months or several weeks when snow, at all but the highest levels, is melting. The annual peak flow occurs during this period, sometimes early or sometimes late in the period, depending principally upon seasonal variations of temperature in the watersheds.

Analyses of volume and peak-flow data for streams draining several western watersheds show a consistently positive trend in relationships between volume and flow. Rivers exhibiting this trend include the Salmon River in Idaho, the Kootenai River in Canada and Idaho, the Dolores River in Colorado, and the Ogden and Weber Rivers in Utah.

Estimating the Peak Flow

Under any given condition of land use, vegetation, and soil, the principal meteorological factors which, in combination, serve to produce runoffs of greatest magnitude are as follows:

1. Snow cover on the watershed much above normal in water equivalent.
2. Continuation into the later part of the normal melting period of above-normal snow-water equivalent in snow storage on the watershed, due to unusually cold weather during the early part of the customary melting period.
3. Sustained above-normal temperatures in the watershed as a whole, setting in during the later part of the usual melting period. This ordinarily leads to concurrent melting of snow on southern and northern feeder streams, which in turn is likely to produce extremes of high water in the main stream.
4. Above-normal precipitation on the watershed during the period of greatest water contributions from snowmelt. (This condition aggravates a flood but is not always essential for a major flood, since temperatures above normal, if a large amount of snow is present, can cause a flood of major proportions.)

These four conditions occurred simultaneously during the major Columbia River flood of 1948, as well as in the earlier disastrous flood of 1894.

There is a definite relationship between the volume of discharge of a snow-fed stream during the major melting period and the peak discharge during this period. This correlation between runoff volume and peak discharge, which is only approximate for the April-May-June melting period, becomes more clear-cut as melting progresses and the period remaining for melting is shortened. Figure 5, based

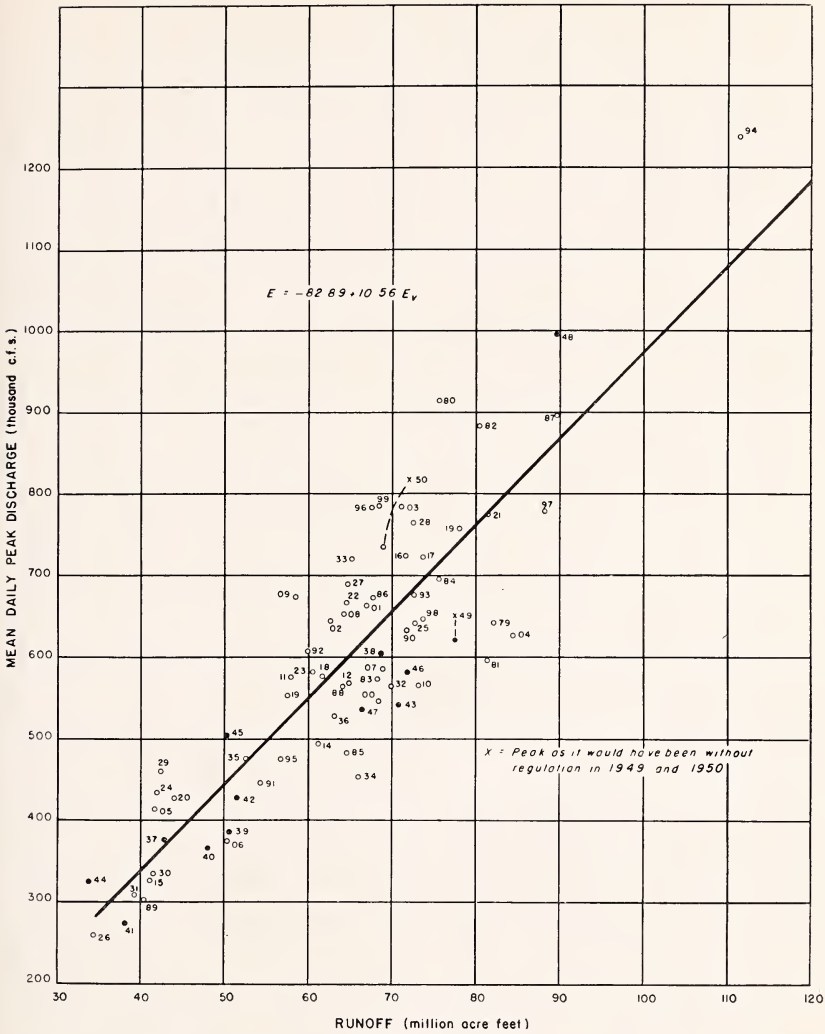


FIGURE 5.—Relation of peak discharge to April-June runoff volume for Columbia River at The Dalles, Oreg.

on April 1 measurements, illustrates this relationship for the Columbia River for the April-June period. (In this and the two following figures, the points plotted as solid circles are years for which there are snow-survey records. Open circles are for other years that provided data for the correlations.)

The probable peak flow, based on April 1 conditions, is found by locating the value of the flow volume on the runoff scale, projecting this point vertically to its interception on the curve, then horizontally to the peak-discharge scale.

Although this chart shows some wide differences in the runoff of individual years, there is an unmistakable correlation between runoff and peak discharge. This relationship provides the basis for the first

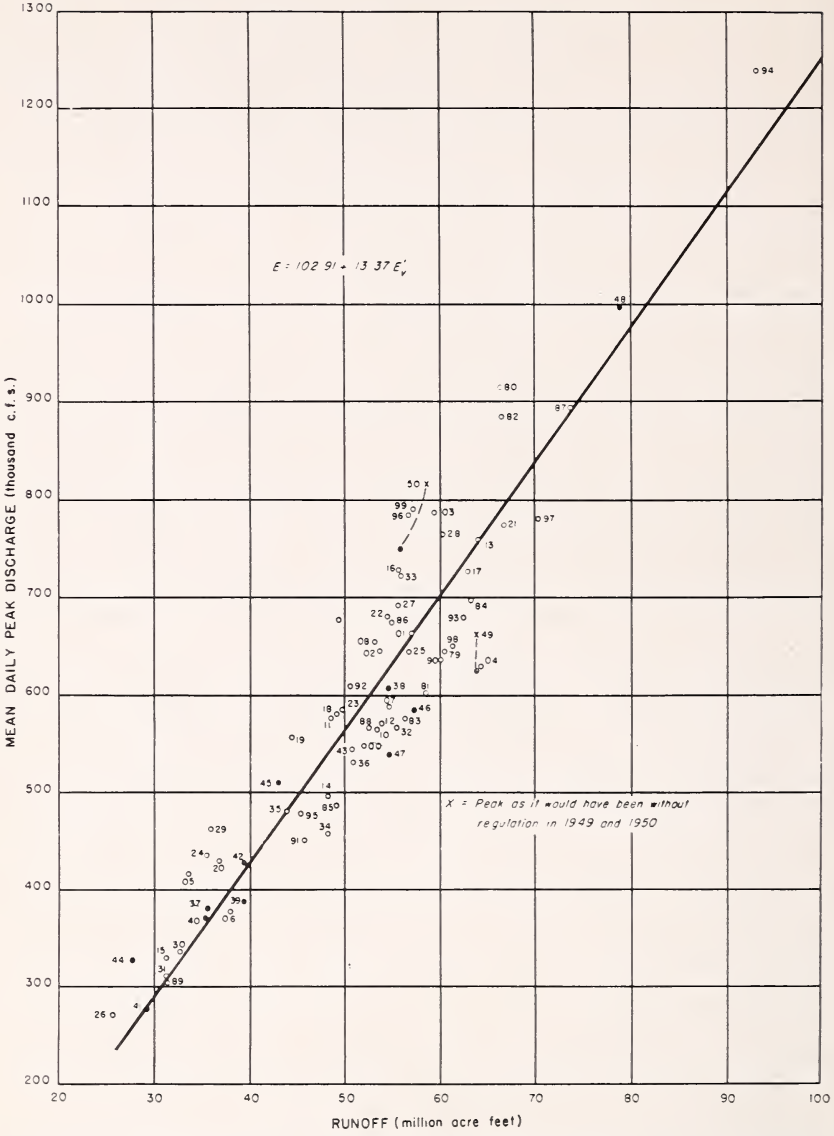


FIGURE 6.—Relation of peak discharge to May-June runoff volume for Columbia River at The Dalles, Oreg.

of a series of approximations of the potential maximum seasonal peak flow on this river. For example, the small volumes of flow in 1940, 1941, 1942, 1944, and 1945 were associated with low discharge peaks in those years. This indicates that if the potential volume of flow in any year is small, the possibility of a high peak flow is remote. On the other hand, in years similar to 1894, 1897, 1948, and 1950 a major flood would be indicated.

The estimate made on the basis of April 1 conditions assumes that average temperature and precipitation over the watershed will prevail through the April-June period. However, if the water content of the snow cover should increase with the advance of spring, or if snow melt should be retarded, the flood hazard would increase. It is important, therefore, to make successive estimates of flow volume during the major snow-melt period. Each additional measurement of snow cover or precipitation, or both, made during April and May prior to the date of peak flow makes possible the formulation of more accurate volume estimates. The estimates become more precise as the season advances and the remaining volume of potential snowmelt in a given period becomes smaller.

Errors in predicting volume of flow from snow water and precipitation, or in determining the relationship of the peak discharge to volume during a given period, may lead to errors in discharge estimates. Hence, any procedure designed to improve the volume forecast will increase the accuracy of the peak-flow estimate. Additional measurements of snow cover on April 15, May 1, and May 15 serve to greatly increase the accuracy of the estimates. Such improved estimates give to users of irrigation water, power-plant operators and stream-flow dispatchers a sounder basis for planning as the season progresses.

In these later estimates, allowances are made for significant weather changes that take place after the initial or previous volume forecast, and for volume of runoff during the intervening period. Thus, the April-June volume forecast is corrected on May 1 for abnormal precipitation and melting during April through the use of May 1 snow-survey records and April precipitation records, and by subtracting the amount of water which ran off during April from the estimated total volume expected during the April-June period. This subtraction compensates to a degree for abnormal climatic conditions during April. The residual value is entered on the volume-peak discharge curve for May-June only (fig. 6). The probable peak discharge as indicated on May 1 is found by locating the value of the reduced flow volume on the corrected graph, then projecting this point to the curve and across to the peak-discharge scale in the same manner as for April 1.

A similar procedure is followed on May 15 to obtain a still closer estimate of the peak discharge. The relationship of peak to volume, revised as of May 15, is shown in figure 7.

The date of the last estimate needed for a particular river basin can be roughly determined from the flood history. For example, during the period of record, which goes back to before 1894, there has never been a Class-A flood [2] on the lower reaches of the Columbia River prior to May 24. As the peak discharge on this stream usually occurs shortly after May 15, measurements of snow cover after this date would indicate only the rate of melting and the probable length of period of high water flow, and would be of limited practical use in estimating peak discharges. Correcting the volume forecasts and peak-flow estimates up to May 15 reduces the estimating error to a point which, for all practical purposes, is small.

[2] Class-A flood on the lower Columbia River is defined by the Corps of Engineers, Department of the Army, as a flow that equals or exceeds 725,000 cubic feet per second at The Dalles.

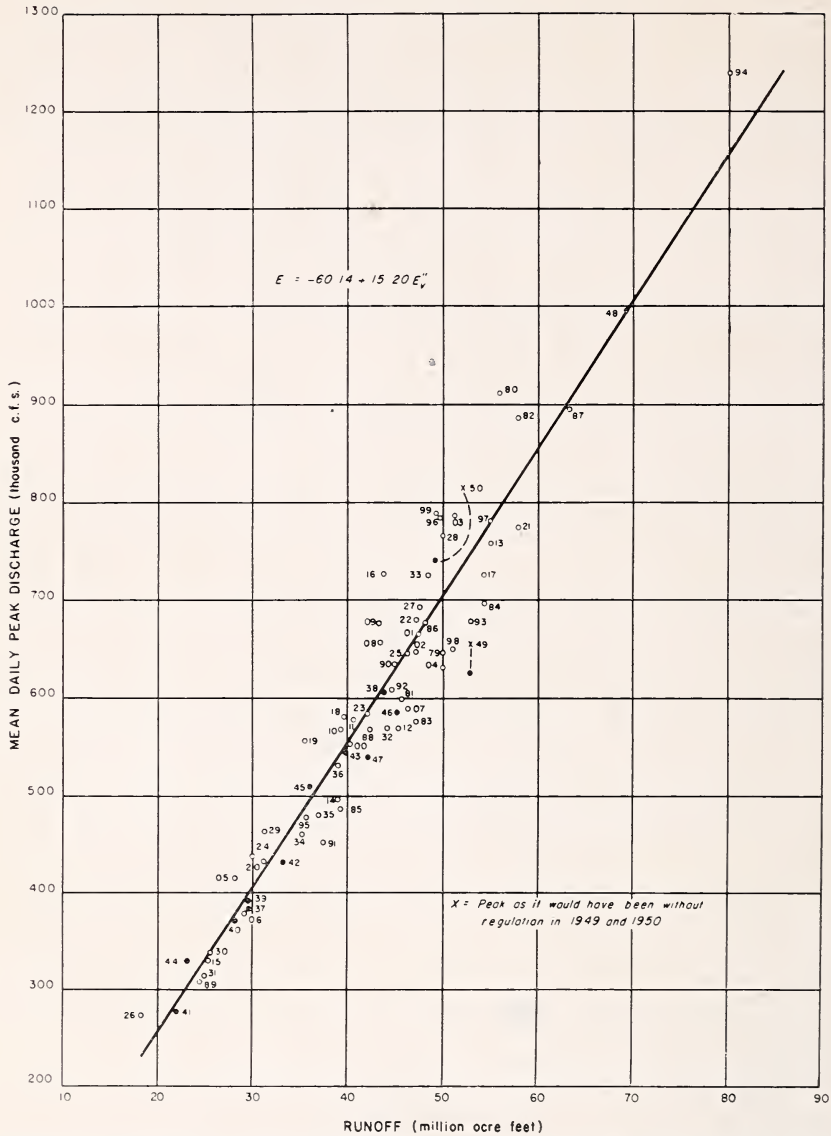


FIGURE 7.—Relation of peak discharge to May 16-June 30 runoff volume for Columbia River at The Dalles, Oreg.

The inclusive range of dates marking the beginning and end of the annual period in which high runoff occurs should be carefully determined for any particular river from a study of past records and other data. This permits selection of such dates of forecasting or estimating as will provide the best results under the conditions peculiar to that particular basin. Thus, the tenth and twentieth days of the month might provide a more suitable estimating schedule than the 15-day interval used in the Columbia River example. Estimates could even be revised weekly if their value were sufficiently

great to warrant such refinement. And for some streams, establishing the relation of peak to volume for periods only up to June 1 or June 15 might be more effective than for periods extending beyond these dates.

Snow surveys deal primarily with estimates of probable total volume of flow that are required for irrigation and power uses. The method described herein for estimating both total flow volume and peak flow also provides a means of using snow-survey data in planning for effective flood control. It should be noted, however, that in making the necessary correlations for flow volume and peak discharge by this method, any errors made in determining the basic snow cover-runoff relationship will be carried over from the predicted volume into the estimate of peak. Occasionally errors made in the various steps of calculation compensate one another and thus do not cause any net change in the final result.

BENEFITS OF STREAM-FLOW FORECASTING

Melting of the snow starts a process which, when properly controlled in its various stages, results in a whole chain of profitable water uses. Water stored primarily to prevent damaging floods or to assure irrigation supplies, after it has been released through the control gates to generate power, may be conveyed to irrigated fields or into municipal mains, or made to serve industrial needs.

Snow surveys provide basic data for predicting whether the seasonal water supply will be adequate, inadequate, or greater than the needs for these various types of use.

In years of short water supply, forecasts of seasonal water supply furnish a reliable basis for necessary modifications in cropping and irrigation plans. Such adjustments may include reductions in the acreage of irrigated land; substitution of forage crops for row crops; the growing of early maturing crops or crops with low water consumption in place of crops which require large supplies of water and late irrigations; and many other measures designed to conserve limited water supplies. Advance warning of impending water shortages, such as those that occurred in Utah during 1934 and throughout the Southwest generally in 1951, afforded time to quickly develop temporary supplies of supplemental water.

On the other hand, in years of heavy mountain snow cover and abundant or surplus stream flow, accurate forecasts of increased water supplies make it possible to plan for bringing additional land temporarily under irrigation. For instance, in 1946 the snow surveys early in the spring indicated that the water supply in prospect for Deschutes and Crook Counties, Oreg., would greatly exceed the average. Accordingly, 6,500 acres of land not normally cultivated were seeded and irrigated that season. The cash value of the successful crops from these additional acres was estimated to be more than half a million dollars.

Among many other illustrations, the control of Upper Klamath Lake in Oregon offers an outstanding example of the importance of forecasting runoff volume and estimating the peak flow in advance of their occurrence. Although storage in this lake always provides enough water to satisfy the earliest recognized rights of irrigation-storage users, it does not in all years provide sufficient water supple-

mentary to natural flow to meet yearlong hydroelectric power requirements. Consequently, whenever the inflow exceeds the necessary draft, every possible step is taken to store sufficient water for the supplementary needs.

There is, however, an upper limit of safe storage in the lake which may not be exceeded without danger of damage to industrial or farming areas bordering the lake; nor can the release of water through the outlet channel of the lake be allowed to exceed the maximum safe flow without endangering industrial installations along the channel banks. This problem of optimum storage is particularly acute near the end of the winter rainy period when lake storage usually is relatively high. If the lake level at that time should already be critically high, any inflow in excess of the permissible release rate might cause severe damage to properties around the edge of the lake. On the other hand, if the level should be lowered to provide space for an expected inflow, and the inflow should then fail to appear, the power company would not be able to use its generators to full capacity throughout the year. It is highly important, therefore, to foretell whether the water stored in snow will fill the lake to capacity or is likely to more than fill it.

As in the Upper Klamath Lake area, the mountain snow packs in most of the watersheds of the West are the main source of water for the populated valleys at lower elevations. In this area, and in regions generally where abnormally massed snow poses a menace to human life and property in the lower reaches of the rivers, snow surveys provide a reliable basis for the timely forecasting of water supplies. This is because the snow courses are strategically located high in the mountains at the water sources where experience shows that snow measurements provide data on water content that correlate closely with the records for stream flow.

Furthermore, the snow-course measurements show the residual water content at the survey date. This information, when properly combined with data on the extent to which precipitation and temperature during the melting season depart from normal, provides dependable correlations with total seasonal volume of stream flow and peak flow.

Forecasting by this means has proved highly useful in actual practice. Advance information on the runoff from snowmelt can be used to solve the dual problem of water conservation and flood control in the operation of multiple-purpose reservoirs. Because of their accuracy; seasonal flow-volume forecasts from snow surveys can help to reduce to a minimum the destruction and damage from excessive water flows in areas of the West which are vulnerable to large runoffs. In seasons of more than normal supply they also enable users of water to get full service from the reservoir system by making seasonal use of water which would otherwise be worse than wasted in peak-season floods.

U. S. GOVERNMENT PRINTING OFFICE: 1953

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price 10 cents